

Born to Run – Dual Task Cognitive Effects of Ecological Unconstrained Running

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Young people love what is interesting and odd, no matter how true or false it is. More mature minds love what is interesting and odd about truth. Fully mature intellects finally, love truth, even when it appears plain and simple; boring to the ordinary person, for they have noticed that truth tends to reveal its highest wisdom in the guise of simplicity. Nietzsche

Truth: patient and relentless

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1. ABSTRACT

The interaction between exercise and cognitive task performance has been previously examined using cycle ergometer and treadmill running tasks. The interaction between natural (non-constrained) exercise and cognitive task performance has, however, been less well examined. An example of a natural exercise task would be running outdoors on a steep trail where route selection and foot placement are critical for the runner. The performance of runners is examined in a dual trail-running and working memory task. The working memory task involved counting tones and was performed at both a low workload, in which they were asked to count every fourth low frequency tone and a high workload in which they were asked to count every fourth low, medium and high frequency tone. In experiment one, runners performed the tone-counting tasks both while running on a steep trail with uneven terrain and while seated (control conditions). In addition, they ran the trail without a cognitive task load. Running distance and counting accuracy significantly decreased during the dual task trials, there was a linear trend, as the task got harder, running distance decreased. Cognitive performance was only significantly impaired while running for the hard cognitive task condition (for the easy cognitive task there was no statistically significant difference). Participants reported an increased workload in the dual run-counting task conditions when compared with the seated task conditions. Reports of task focus and feelings of being spent (exhausted) also varied across task conditions. In experiment two, unconstrained running was conducted in the same manner on a flat-even terrain track to establish if the route selection and scanning required to negotiate uneven terrain was causing the dual-task interference, or if there is a general interference effect caused by the self-regulation demands of running, or the direct demands of running itself (exercise). The linear trend, of decreased running performance with increased secondary cognitive demand was similar to experiment 1 - the more cognitive load the less distance travelled. The effect on the cognitive task was,

however, not evident in experiment two; there was no statistically significant difference between cognitive task performance in the dual and single-task conditions. The findings outlined in these experiments, demonstrate dual cognitive tasks have a negative effect on running performance, and the cognitive task may also be affected depending on running intensity, particularly where self-paced natural running over terrain is coupled with complex cognitive tasks.

Keywords: Attention; dual-task; running; tone-counting; working memory

2. INTRODUCTION

2.1 Positive and Negative Cognitive effects of exercise

Exercise researchers have studied the positive psychological effects observed during, but predominately after, exercise. Exercise increases the performance on reaction time tests and simple decision making tasks, however these effects cease immediately after exercise (Etnier et al 1997; Dietrich & Audiffren 2011). Evidence has shown exercise reduces stress, anxiety and depression (Salmon 2001) and has physical benefits for cardiovascular systems, reducing renal disease, diabetes and osteoporosis (Fentem 1994). Runners typically experience positive emotions, analgesic and sedation effects, and feelings of wellbeing which last well into the post exercise period (Dietrich & Audiffren, 2011). Post endurance exercise shows a significant increase in euphoria coupled with increased opioid binding in the prefrontal cortex which provides an explanation for the ‘runners high’(Boeker et al 2008; Dietrich & Daniel 2004). Due to experimental constraints, these effects can only be tested post exercise, and little is known about cognitive processes during exercise. Until recently the commonly held view has been that exercise has positive cognitive effects, however reviews of exercise literature demonstrates many contradictory findings (Dietrich & Audiffren 2011). Dietrich & Audiffren’s (2011) reviews uncover that on a whole, although there are many positive cognitive effects of exercise, there are also many negative effects, with research suggesting that prefrontal regions may be negatively impaired by exercise.

Research highlighting the negative psychological effects occurring during exercise has also been conducted (Labelle et al. 2013). These researchers found as exercise intensity increased, the negative effect on performance increased, and also the less fit participants showed greater variability in performance. Kubitz and Pothakos (1997) found an increase in

alpha waves, particularly in the frontal cortex, following exercise which indicates a decrease in brain activation. Other researchers have examined dual-task costs which may occur when a cognitive task is being performed during rock climbing (Green and Helton 2011; Green et al. 2013). Performance was not affected for the distances climbed over a rock wall however the dual memory task was significantly effected which suggests a selection for attention based on needs (not falling is more important than getting tasks correct).

The interaction between exercise and cognitive task performance is complex with two general mechanisms resulting in potentially opposing effects: arousal-induced resourcing and direct resource competition (Dietrich and Audiffren 2011; Lambourne and Tomporowski 2010; Tomporowski 2003; Tomporowski and Ellis 1986). A mechanism by which exercise may result in improvements in cognitive task performance, during, but also after, the cessation of exercise, is by increasing energetic arousal. Exercise increases cortical arousal (Lambourne and Tomporowski 2010). Increased energetic arousal has been found to improve cognitive task performance, independently of exercise (Helton and Warm 2008; Helton et al. 2009; Langner et al. 2010; Matthews and Davies 2001; Matthews et al. 2011). The theoretical mechanism proposed, states that arousal results in increased cognitive resource utilization and/or availability in line with exercise induced arousal, researchers have found improvements in simple reaction time tasks and speeded visual search tasks during exercise (McMorris and Graydon 1997; McMorris and Hale 2012; Shields et al. 2011). However as one system is boosted, another is weakened. The prefrontal cortex shows decreased function which is demonstrated in dual task activities and animal research (Vissing et al 1996). Contradictory findings regarding the cognitive effects of acute exercise are to be expected given the complexity of the methodology and type of cognitive tasks applied, intensity, cognitive function, fitness level, duration, modes, exercise type and the time of measurement

are just some of the confounds which draw conflicting conclusions around the brain's processes and substrates while exercising, particularly, the role of the frontal cortex and the executive function during exercise (Labelle et al 2013).

2.2 Brain Metabolism and Blood Flow While Exercising

Providing a physiological basis for this contradiction in performance Vissing et al (1996) studied the glucose utilisation of running rats. They found an increase in glucose utilisation in the motor, sensory (including the visual and auditory cortex), autonomic functions and in the white matter, cerebellum and corpus collosum. Total glucose utilisation increased, but the localised utilisation also changed. The prefrontal cortex, the inferior olive which projects sensory information to the cerebellum, ventromedial hypothalamus and median raphe which make adjustments to the autonomic system during exercise did not increase glucose utilisation. In summary, there was an increase in global and localised brain glucose utilisation, and a decrease in other areas, meaning certain parts are utilising an increased resource to the detriment of other brain regions. Similar findings were demonstrated when measuring the cerebral blood flow (CBF) of dogs. Gross et al (1980) found that during moderate exercise, there was no increase in total CBF to the brain. There was however an increase in regional blood flow which was localised to the motor sensory cortex, neocerebellar and paleocerebellar cortex and spinal cord, all regions associated with motion. The total blood flow resource remained the same, however the allocation to various regions changed significantly, which in turn meant other parts of the brain received less resourcing (blood flow). This shift in local resource allocation, appears to be triggered during whole body exercise.

2.3 Multiple Resource Theory

Attention is a limited resource (Horrey et al. 2006; Wickens 1976; Wickens and McCarley 2008). The brain is not equipped to dedicate all its resources to all processes all of the time and so it has to select or attend to certain stimuli over others (Wickens 2002). Wickens (2008) has proposed a multiple resource theory (MRT) account of human attention in which attention resources are separated on three major dimensions: stages of processing (perception, cognition, or action), codes of processing (spatial and verbal or symbolic – subsequent studies would also suggest a separate object code), and sensory channels and modalities (visual, tactual, and auditory). The MRT perspective is based on both behavioural and neurophysiological data suggesting that when tasks simultaneously tax one or more of these systems there are performance interference effects, as they compete for overlapping or limited processing resources. The closer in overlap two tasks are, in which process stage of resources they demand, the more likely they will interfere and performance will decrease. For example, two tasks both predominately placing demands on spatial processing will interfere more than a task which is predominately verbal and one that is predominately spatial (Helton & Russell 2011). Utilization of different processing resources does not, however, negate the impact of total resource demand (overall cognitive load). Even two tasks not overlapping extensively in the kinds of neural resources utilized may still result in interference if the overall demand of the two tasks is high. Where the two high demand tasks overlap in resource utilization, and presumably to some extent all tasks will overlap to some extent, the high demand of the two tasks may still result in competition and thus, interference. As Navon and Gopher wrote (1979: 214), “The human system employs utility considerations to decide on allocation of its limited resources.”

2.4 Dual tasks and attention

Exercise and a concurrent cognitive task may interfere with each other by competing for attention and limited cognitive resources. In laboratory studies typically employing two concurrent cognitive tasks, interference effects, or dual-task costs, are common (Bourke et al. 1996; Helton and Russell 2011; 2013; Woodworth and Schlosberg 1955). These dual-task interference effects are also found when whole body movement is combined with cognitive tasks (Green and Helton 2011; Green et al. 2013; Lindenberger et al. 2000; Yogev-Seligmann et al. 2010). These effects are typically greater when the two tasks, both the movement task and the cognitive task, are more challenging, requiring greater working memory and executive resources (Labelle et al. 2013). Indeed, in a recent meta-analysis, Lambourne and Tomporowski (2010) found greater cognitive task performance costs in studies using treadmill running than stationary cycling, presumably because of the greater demands of balancing on a treadmill than balancing on a stationary cycle. Sport, particularly technical running, requires directed attention. Knowing ‘where’ and ‘when’ to look are crucial to performance and injury prevention. Williams et al (1999) suggest, with practice and experience, athletes develop a knowledge base formula for visual searching, which direct the visual search and attention to demands. Therefore the more experienced the athlete the more appropriate their focus of attention is likely to be. This ‘brain fitness’ is likely to increase performance in dual tasks experiments as more attentional resource can be dedicated to the cognitive task.

2.5 The Reticular Activating Hypofrontality Theory

Full body exercise is likely to place heavy demands on the brain’s limited resources and theories are developing to explain cognitive resource allocation during exercise. A case in point is the reticular-activating hypo-frontality (RAH) model suggested by Dietrich (2006).

The RAH model proposes that exercising results in generalised brain activation via the brain's arousal networks, full body strenuous exercise forces the neural system to make economic trade-offs. Motion control, in particular full body movement, is computationally demanding, the brain needs to redirect resourcing to systems of the brain most useful in controlling motor action (Dietrich and Audiffren 2011). For motor activity to be smooth and unhesitant, motor control should largely rely on the implicit (unconscious) cognitive system. Excessive control from the explicit (conscious) system may cause performance disruption (Beilock et al 2002). The explicit cognitive system, which consists of working memory and executive control, entails extensive activation of the frontal cortex. The implicit system entails activity of more caudal areas of the brain, for example increased activity in the basal ganglia, cerebellum, and supplementary motor cortex. Thus, the RAH model proposes that intense exercise should cause reduced frontal activity and enhanced activity in more caudal parts of the brain. Regardless of the veracity of the RAH model, the model plays an important role in raising the issue of resource allocation during dual-task situations involving full body locomotion (Dietrich and Sparling 2004). Indeed, like MRT, the RAH model also makes the point that the brain's processing systems may be construed as multiple interacting and potentially competing entities.

2.6 State Self Reporting

Self reporting of subjective affective states has long been used in psychology (Mathews et al 2002). More specifically there is a clear distinction between affect, motivation and cognition (Mathews et al 2002). Measuring states and not traits means the researcher can gain information on the immediate context rather than the typical subjective experience. "A subjective state may be defined as a relatively transient quality permeating conscious awareness whose representation is distributed across a variety of mental processes or

structures, and which has the potential to generalise across activities and contexts” (Mathews et al 2001: 316). Collecting varying subjective measures of state, gives a comparative workload state, confirming whether a participant’s task experience, as difficult or easy, are parallel to the researcher’s predictions.

2.7 Goals of Present Research

In this research project the performance costs of performing trail running while also performing a secondary auditory tone counting task of varying task difficulty was investigated. Running over uneven terrain should place heavy demands on the neural motor control system. Many of the studies investigating the effects of concurrent exercise on cognitive processing have used physical exercise that is cyclical and performed in constrained artificial environments, such as treadmill walking, running, or stationary cycling (Lambourne and Tomporowski 2010). While employing a constrained movement task has merits, for example safety and ease of data collection, this unfortunately may reduce the cognitive costs of exercise-locomotion below those likely to occur in more realistic settings. Full body locomotion in natural environments is not simply a matter of exercise and physical load, but also requires dexterity and motor planning to deal with obstacles and surface variation and the suppression of interfering environmental factors like wind. Anyone who has run on a treadmill and then run outside on a trail is aware of this difference.

The processing demands of trail running are expected to be higher than the processing demands of more constrained movement tasks (treadmill running/walking and cycle ergometers). In line with a resource theory account of dual-task performance, we expect that while running may increase cortical arousal, the interference costs will largely outweigh this benefit, especially as cognitive task demands increase. A tone counting task was selected

as this task can be ramped up in difficulty and it also minimizes the amount of non-central interference between the cognitive task and trail running (Brill et al. 2003). Therefore, interference demonstrated by this task can be analysed to establish if intensity increases the negative effects. It is expected that dual-task interference costs, in terms of either reduced running speed or reduced tone counting accuracy, will increase as the difficulty of a secondary cognitive task is increased in comparison to single-task controls. In addition, self-reports of workload and stress will be collected and collated. The aim is to examine whether subjective workload increases as the difficulty of combination of tasks increases. This will be examined in two experiments. In experiment one, running over uneven varying terrain (trail running), in experiment two, running on an even non-varying flat running track (track running). Experiment two is designed to be more similar to the cognitive demands of treadmill running and indeed the original intent was to conduct the experiment on a treadmill, but this raised methodological challenges. As mentioned previously, the majority of research on dual-task effects during exercise use constrained laboratory exercise (treadmills and cycle ergometers). This work has some significant advantages (increased experimental control of the running task). The present research, however, takes a different approach to the problem and starts in the wild with a fully ecologically realistic running task (experiment one) and then works back to more constrained tasks (experiment two). The goal is to eventually have both, constrained exercise research and unconstrained ecologically realistic research, to interface and converge on the issue of cognitive resource allocation during full body movement tasks.

3. EXPERIMENT ONE

Green & Helton (2012) used a climbing, dual memory task to examine the MRT theory that task performance was effected by whole body exercise, however no known studies have coupled trail running with a dual working memory task. Lindenberg et al (2000) found significant effects on dual tasks while testing gait in elderly participants who were required to maintain walking while completing an additional task. Dual task costs increase with age, suggesting as more attention was required to maintain gait, less was available to attend to the dual task. In addition to this Hollman et al (2009) found men walked with greater stride by stride variability during dual tasks than woman did, which suggests there can be many factors associated with dual task performance and whole body motion. Inconsistency exists however, as to whether the dual task performance or the physical activity will be affected, or both. For example in a rock climbing task it would be expected that one would prioritise not falling, over a memory task. Labelle et al (2013) found cyclists accuracy on a dual stroop task was affected as intensity increased. “Error rates increased as a function of peak power output” (Labelle 2013). Given the increased muscle usage while trail running up hill, it is expected that these results would be similar if not more defined due to the difficulty of the environment which automatically amps up the intensity. Subjective reports from experienced runners proposes that trail running is considerably more challenging, both mentally as well as physically, than treadmill running or cycling. Also, when suppression of stimulus is required it increases the workload of the attentional systems, which impairs performance on cognitive tasks (Helton & Russell 2011). Interference from the elements, when taking running experiments off the treadmill and out of the laboratory include; wind, heat, sound and environmental distractions. The suppression of stimulus will surely only add to the attentional deficit experienced during real world running. This increases the attentional demands of

participants, more so than treadmill running, also given trail running requires both gait control, scanning and route selection it is expected to see effects to either distance or task performance or both.

3.1 Hypotheses

3.1.1 Running and dual task performance

Hypothesis 1: A dual secondary counting task will reduce the running speed (or distance covered) of trail runners in comparison to running speed when there is no secondary task. More specifically, trail running distance (speed) will decrease as the difficulty of the counting task increases.

Hypothesis 2: Trail running will reduce counting task performance when compared to not trail running and completing the counting task.

Hypothesis 3: Performance on the counting task will decrease as the difficulty of counting task increases.

3.1.2 Subjective workload and Self-Report Stress State

Hypothesis 4: Participants will report the counting tasks harder (more cognitive workload) when coupled with a running task, than when performed alone.

3.2 Method

3.2.1 Participants

12 athletes (9 males) participated in the study. Participants were recruited from sporting events and personal coaching businesses. The criteria for participation were to be of reasonable fitness (exercising a minimum of three days a week) and to be experienced at trail running. The mean number of years participants reported running on a regular basis was $M=13.04$ and participants' best event included the Kepler challenge (60km mountain run), full (42 kms) and half marathons (24 kms), Avalanche Peak (1833m summit mountain run) and the coast to coast (267km multi-sport race). Ages ranged from 29 to 45 years ($M=37.91$, $SD=5.19$). All participants were fluent speakers of English. Athletes were compensated for their time with a voucher and went into a draw to win a pair of top end running shoes. This experiment was approved by the University of Canterbury's Human Ethics Committee. All participants were treated in accordance with the ethical guidelines.

3.2.2 Materials

The experiment was conducted on a 0.66km trail in the Port Hills of Christchurch. The trail was at an average 8 degree gradient, and included steps, rocks, mud, bridges and gravel to negotiate. Some sections of the trail involved climbing a stile and large rocks. Participants were required to wear a safety helmet to protect their heads in the event of a fall. Participants wore their own running clothing and shoes. The track was measured with a 50m Komelon tape measure, and pegs were placed at 5 m intervals from a datum point on the track, where it was believed all runners would reach, these were later added to the total below that point. See Figure 1 for a picture of the running trail.

Figure 1: Trail running track – 0.66 km and elevation in metres



Auditory Tone Counting Task. The auditory tone-counting task was developed from the Kennedy counting task (Kennedy & Bittner 1980). Test re-test reliability for the auditory counting task is $r = 0.79$ (Kennedy & Bittner 1980). A cell phone application was developed by Lafayette Instrument Company, a software development company based in the United States of America (www.lafayette.com). After some development, the resulting application was used throughout the experiment and can be downloaded from the iTunes store (iPsymRT). The App plays tones which have corresponding buttons to respond to the tones. The application was played on an Apple iPhone 4s, and plays three tones which were set to

300Hz, 1100Hz and 2000Hz. These tones were played through full size head phones which are designed to fully seal against the head in order to attenuate external noise. They were plugged in directly to the iPhone. A helmet was used for all running conditions and the headphones were wired securely to the helmet. For each counting task the application was set for 5 minutes total duration, consisting of 99 trials. The tones (low, medium, and high frequency) played in random order and each individual tone played for half a second (500ms). There was a 3 second inter-trial interval between tones. The volume was adjusted to the individual participant's specifications. The subject name and task was added into the dialogue box and results were emailed after each trial. The task has three levels of difficulty: low, medium and high. The tones played do not change (always all three and randomly presented with equal probabilities), only the number of tones attended to changes the difficulty of the task. In the easy task participants only count the low tones, and press the corresponding low button on the fourth count. The hard task required participants to count all three pitch tones (low, medium, and high frequency) simultaneously and independently and press the corresponding button on every fourth tone for each frequency (see Figure 2). For the purposes of this experiment only the low and high demand tasks were employed to minimise unneeded data and maximize the difference in cognitive load. Participants were able to press the buttons with three fingers (one for each button) without looking at the screen to avoid visual peripheral interference.

Figure 2: Cell phone interface showing low, middle and high tone buttons



A self-report scale was used as part of the study. This included a modified version of the NASA TLX which consisted of six scales: mental demand, physical demand, temporal demand, performance monitoring demand, effort and emotional demand (Hart and Straveland 1988; modified version Sellers 2013). The additional items were developed specifically for this study: Physical Fatigue, Mental Fatigue, Tense, Unhappy, Motivation, Task Interest, Self-Related Thoughts, Concentration, Confidence, Task Related Thoughts, and Task Unrelated Thoughts. These items were based on the factors of the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 2002), where each factor was summarized by a single item. The questionnaire was given to participants immediately following each task, when it was comfortable for them to complete it. The ratings vary from 0 – very low to 100 – very high.

3.2.3 Procedure

Participants met at the car park of the trail and were given an information sheet which outlined the purpose of the experiment and the conditions they were required to complete. Participants were informed they would be required to perform five tasks: a seated easy counting task, a seated hard counting task, a run with an easy secondary counting task, a run with a hard secondary counting task and a run only. A Latin square design was used to determine the order for each participant. The cognitive tasks (easy and hard) were grouped together for ease of instrumentation and the order of these was counterbalanced across participants. Participants were offered water and given as much time as they needed between each run to avoid fatigue. As part of the experimental design, the running task was set for five minutes as opposed to a set distance for consistency across participants and in order to compare the running data with the seated task data.

A pre-test of the counting task and corresponding buttons was given to participants. They had the opportunity to practise with the buttons and hear their corresponding sounds, and they were all given time to become familiar with the equipment before the experiment started. They were advised they could warm up or stretch in any way they needed prior to the run trials.

Before beginning the experiment, participants were set-up at the starting point. Participants indicated they were ready to proceed and the start of the experiment was marked by a 3-2-1 countdown. This countdown was handled by a research assistant at the start point who was in auditory (via cell phones) contact with another researcher stationed at the end-point of the track. The researchers at both points had synced stop-watches. Participants ran until the five minutes was completed. Participants were instructed to complete the run as

quickly and efficiently as they felt comfortable to do so for the five minute duration. The experiment was concluded by the researcher at the endpoint of the track after the five minute period. Although participant reports indicated they were aware of the cessation of the trial, timing the run independently provided further accuracy of the final distance measurement. The researcher did this by meeting the participant close to the finish and giving a clear 'stop' hand signal, and recorded their finish point visually (when possible with a photograph) which verified the distance travelled.

Run alone condition. During the run, participants were played all three random tones. They were advised they did not need to attend to or count any of the tones. Upon completion of the run the participants distance was recorded by measuring the closest peg (meter). Some participants continued past the measured area to the car park so their distance was recorded with spray paint and measured with the same tape measure later.

Seated counting task. For each of the two seated counting tasks, participants were instructed to sit in the vehicle they came to the study in. They were instructed to have no other distractions, radio, or cell phones during each trial. Participants were instructed they would need to count every fourth tone of just the low tone (easy) or all three tones (hard) for a five minute duration. The participant started each task using the start button and concluded by returning to the menu screen.

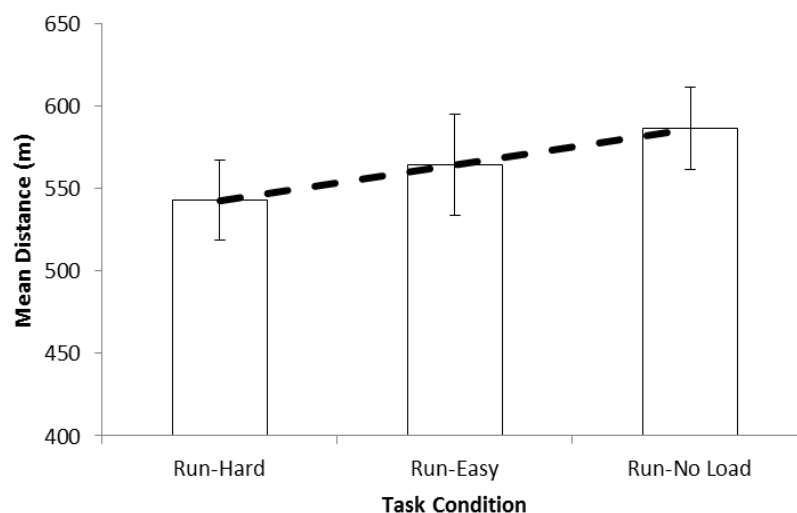
Dual tasks. The two dual task conditions involved a combination of trail running and the counting task. Participants received the same instructions in the seated trials as they did for the running trials. Upon completing each condition the participants were given the NASA TLX questionnaire, which was completed while being driven back to the beginning of the

trail to complete the next running task. Participants were given as much time as they needed to report feeling fully recovered.

3.3 Results

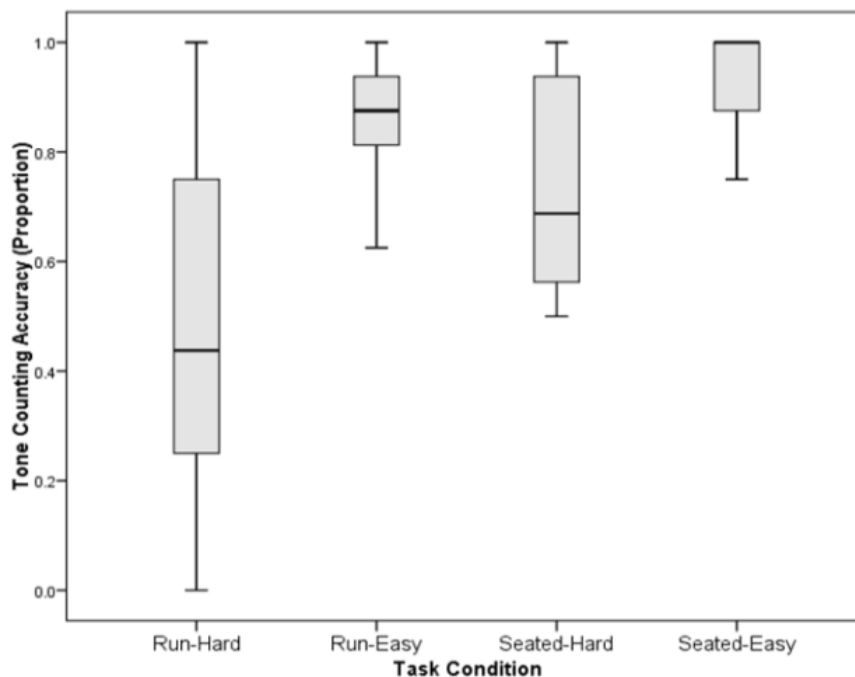
3.3.1 Running Performance. A preliminary inspection of the running performance scores did not indicate any significant deviation from normality (both Kolmogorov-Smirnov and Shapiro-Wilk tests $p > .05$). Therefore, we analysed the scores with a repeated measures analysis of variance (ANOVA). There was a significant main effect for task, $F(2,22) = 6.79$, $p = .005$, $\eta_p^2 = .38$. We performed a trend analysis to test the hypothesis that with decreased cognitive load there would be a trend for increased running distances and there was a significant linear trend as expected, $F(1, 11) = 49.42$, $p < .001$, $\eta_p^2 = .82$. This is displayed in Figure 3.

Figure 3: Trend analysis showing that with decreased cognitive load, there is a trend for increased running distances



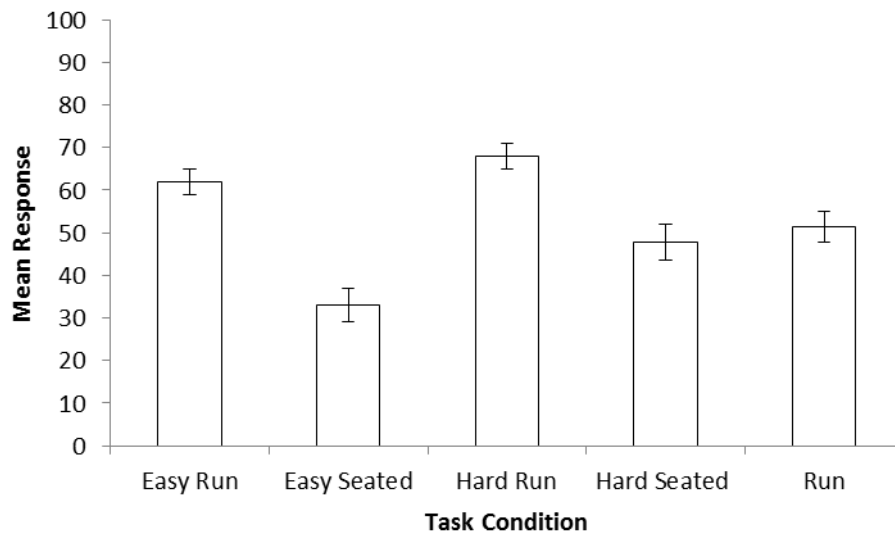
3.3.2 Tone Counting Task. For each participant we calculated the accuracy of the tone counting task for the low frequency tone as this was comparable across all conditions. A preliminary inspection of the tone-counting performance scores indicated significant deviation from normality, both Kolmogorov-Smirnov and Shapiro-Wilk tests $p < .05$. This was not correctable with an arcsin transformation of the data. Therefore, we employed Wilcoxon Signed Rank tests to compare differences between the tasks. The primary comparisons of interest were between the dual-task version (tone counting and running) and the equivalent single-task version (tone counting alone). In the case of the hard task version, there was a significant difference, $Z = 2.67$, $p = .008$, $r = 0.54$. In the case of the easy task version the difference was non-significant, $Z = 1.73$, $p = .084$, $r = 0.35$. We also examined the difference between the two running conditions (running hard and running easy) and the two seated conditions (seated hard and seated easy), and these were both significant ($Z = 2.68$, $p = .007$, $r = .55$; $Z = 2.45$, $p = .014$, $r = .50$). The accuracy (proportion correct) performance for all four task conditions is displayed as box-plots in Figure 4.

Figure 4: The accuracy (proportion correct) performance for all four task conditions for the trail run.



3.3.3 Subjective Workload. The six NASA-TLX items were averaged for each participant for each task to form a composite or global workload score. This global workload score was analysed with a repeated measures ANOVA. There was a significant task main effect, $F(4,44) = 19.43$, $p < .001$, $\eta_p^2 = .64$. Post-hoc Bonferroni corrected comparisons were conducted to further explore this significant effect. Both the easy run and hard run dual-tasks resulted in significantly elevated levels of workload when compared to both seated tasks and the run alone tasks, $p < .05$; however, the two dual-task running conditions were not themselves significantly different. In addition, the run alone task resulted in significantly elevated workload in comparison to the easy seated condition, $p < .05$. The mean global workload scores for all tasks are displayed in Figure 5.

Figure 5: Mean global workload scores for trail run



3.3.4 Self-Report Stress State. Principle components Chain-P factor analysis

(varimax rotation) was conducted on the subjective stress state items for descriptive purposes (see Nunally 1978). P-technique analysis consists of factor analysing the repeated measures from single individuals; when multiple individuals are combined in the analysis this technique is called Chain-P (Baldwin 1946; Cattell et al. 1947; Molenaar 2004; Molenaar and Nesselroade 2009). This technique is useful for uncovering state, as opposed to trait, factors, which is congruent with conceptualizations of stress state. The items were standardized for each participant individually for the 5 tasks (within-subjects z-scores), and then these standardized scores were combined across participants for the analysis (chained). This resulted in 60 records for the factor analysis. In this analysis, the following criteria were used to determine factor structure: eigenvectors greater than 1, an examination of the Scree plot, and interpretability. Presented in Table 1 are the resultant rotated pattern matrices.

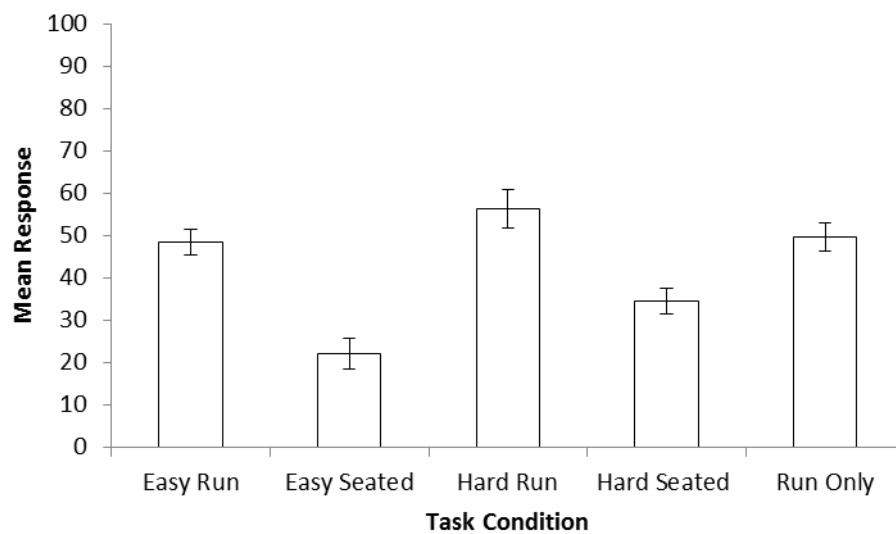
Table 1. Rotated factor matrix for the stress items

	Component	
	Spent	Task-Focus
Physical Fatigue	0.719	
Mental Fatigue	0.651	
Tense	0.708	
Unhappy	0.707	
Motivation		0.607
Task Interest	0.590	
Self-Related Thoughts		-0.524
Concentration		0.821
Confidence	-0.718	
Task Related Thoughts		0.816
Task Unrelated Thoughts		-0.691

The analysis resulted in a two-component solution, Spent and Task-Focus, which collectively explained 51.2% of the variance. Selection for retention of items was based on a component loading $> .4$ (Nunally 1978). Items loading negatively onto a component were reversed scored. The component scores were created by then averaging the remaining items. The Spent component represents the degree to which the participant felt burnt out or exhausted by the task. The Task-Focus component represents the degree of task-focus the participant reported in response to the task. Both component scores were analysed with repeated measures ANOVA. In the case of Spent there was a significant difference across tasks, $F(4,44) = 22.13$, $p < .001$, $\eta_p^2 = .67$. Post-hoc Bonferroni corrected comparisons were conducted to further investigate this effect. The three running conditions were not

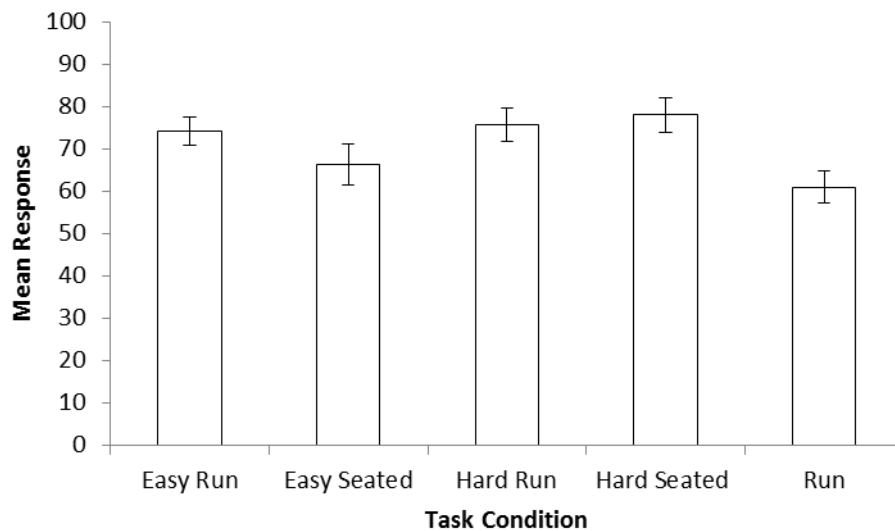
significantly different from each other, but they were all significantly elevated in comparison to the seated cognitive only conditions, $p < .05$; however, the seated cognitive conditions were not themselves significantly different. The mean responses for Spent for all five tasks are presented in Figure 6.

Figure 6: Mean subjective feelings of being spent across conditions



In the case of Task-Focus there was a significant difference across tasks, $F(4,44) = 4.14$, $p = .006$, $\eta_p^2 = .27$. Post-hoc Bonferroni corrected comparisons were conducted to further investigate this effect. The only significant difference was between the hard run condition and the run alone condition, $p < .05$. The mean responses for Task-Focus for all five tasks are presented in Figure 7.

Figure 7: Mean subjective feelings of Task-focused across conditions



3.4 Discussion

As predicted, dual-task costs occurred when trail-running was paired with a tone-counting task. This dual-task cost was only statistically significant, however, when the tone counting task was higher in cognitive demand. Not only did running distance decline as the cognitive demand of the cognitive task increase (see Figure 3), but accuracy on the cognitive task itself was only significantly impaired when the task was more cognitively challenging. These findings may provide evidence supporting either the RAH model (Dietrich and Audiffren 2011) or a model in which trail running and the tone counting task are themselves competing for executive or directed attention resources (Green and Helton 2011).

Using the RAH model to account for results, the motor control system necessary for running is competing for limited resourcing with the executive control system necessary for tone counting. The performance interference effects found here would appear to fit with this model. The demanding tone counting task is impaired when performed while trail running, as opposed to when the task is performed in a seated control. There are, however, two potential

issues for the RAH model as an explanation for these particular experimental results. First, an important feature of the RAH model is the total duration of the exercise task; as the exercise task continues, the brain system resourcing difference accumulates (Dietrich and Audiffren 2011). Given the current running tasks were only 5 min in duration, perhaps, this is not an adequate time for the RAH model to take effect. Second, we found only the hard cognitive task was significantly impaired by running. While in theory the competition between the motor control system and the executive control system would be bidirectional, the general orientation of the RAH model is directional. In the RAH model, the brain ensures the effectiveness of whole body activity which is more evolutionarily primary (primitive) by down regulating the executive control (explicit) system which is construed as a late evolutionary add-on. Given the relatively short time running (5 min), which was nowhere near the maximal amount tolerated by these runners (who are regular long distance runners), one would expect the interference cost would show up relatively quickly for running performance.

While the RAH model has an elegant simplicity which explains a wide-variety of findings, the dual-task costs found here may also support the view that trail running itself places demands on the executive system. While motion control may be fairly automatic and implicit, trail running does require decision making. When choosing a route, foot placement and angle are certainly in part based on previous experience and associative rules learned about what constitutes stable ground or a less effortful route, but there may be an amount of higher level decision making occurring regarding route selection on an unpredictable trail. In this regard trail running could be analogous to driving (Horrey et al. 2006). Like trail-running, driving requires route decision making. Unlike trail-running, driving places relatively low demands on the motor control system as conceptualized in the RAH model

(driving is not usually physically intense), yet driving does demonstrate dual-task interference costs with cognitive tasks (Horrey et al. 2006; Wickens and McCarely 2008). Thus route decision making requiring executive or directed attention may be the element causing interference in the present experiment. Thus, a cognitive demanding task may slow down route decision making.

Another possibility is that running when there is really no external prompt to do so, for example, a predator chasing after you or a prey fleeing from you, requires executive resources or directed attention. The interference, therefore, between trail-running and tone counting may be due to limited directed attention or self-regulatory control (Langner and Eickhoff 2013). A number of researchers have demonstrated a link between volitional willpower and directed attention (Muraven and Baumeister 2000). Perhaps increased mental workload reduced the ability of the executive system to impel the person to run, hence they slowed down (e.g. went easier) when loaded mentally. Running fast without an external prompt, while undoubtedly pleasurable for some, is probably a task we have to volitionally force ourselves to do. Indeed, in the present study people reported feeling more Spent after the running tasks than the seated control tasks. Sitting and doing even a challenging tone counting task for 5 min is much less subjectively fatiguing than running fast even without a mental task for 5 min. Volitionally forcing oneself to run fast may be particularly challenging when our attention or executive resources have been consumed or reallocated to a challenging mental task. People are presumably consciously aware of the challenge of doing both running and tone-counting, as subjective workload was highest in the dual-task settings and self-reports of Task-focus was higher in the high demand run than running alone.

Placing fewer demands on route decision making may help determine the degree to which the performance interference seen here was due to the trail running requiring route decision making versus simply running.

4. EXPERIMENT TWO

In order to tease out the effects of running on cognitive resourcing, an investigation is required on a flat track where there is less route selection and terrain negotiation demands than on a trail run. Several studies have used treadmill running to examine cognitive effects (Dietrich & Sparling 2004; Boutcher & Lander 1988), however given the initial experiment was located in an uncontrolled environment; this experiment would need to be also. In order to compare results to the initial experiment, where free running and pace setting was self-directed, and to further explore the cognitive effects of trail running, self-regulation and volitional control, free running on a track was selected. This would assist in clarifying whether the detriment found in experiment one was due to limited directed attention due to the demands of negotiating uneven varying terrain, or to the volitional and global attention demands of self-regulated running itself (exercise).

4.1 Hypotheses

4.1.1 Running and dual task performance

Hypothesis 1: A dual secondary counting task reduces the running speed (or distance covered) of track runners in comparison to running speed when there is no secondary task. Specifically, performance on track running distance (speed) will decrease as the difficulty of the counting task increases (linear trend).

Hypothesis 2: If self-regulated running is itself depleting of central executive resources and it is not the additional burden of negotiating uneven terrain, track running will reduce counting task performance, especially for the difficult cognitive task, when compared to single-task control cognitive tasks

Hypothesis 3: Performance on the counting task will decrease as the difficulty of counting task increases.

3.1.2 Subjective workload and Self-Report Stress State

Hypothesis 4: Participants will report the counting tasks harder when coupled with a running task

Hypothesis 5: Participants subjective reporting of being spent will increase as dual task workload increases

Hypothesis 6: Participants subjective reporting of task focused will increase as dual task workload increases

4.2 Method

4.2.1 Participants

Thirteen (10 males) athletes participated in the study. Participants were recruited from sporting events and personal coaching businesses. The criteria for participation were to be of reasonable fitness (exercising minimum three days a week). The mean number of years participants reported running on a regular basis was ($M=15.46$, $SD = 13.47$) and participants best event ranged from the Kepler challenge (60km mountain run), full (42 kms) and half marathons (24 kms), Avalanche Peak (1833m summit mountain run) and the coast to coast (267km multi-sport race). Ages ranged from 29 to 45 years ($M = 36.07$, $SD = 12.01$). All

participants were fluent speakers of English. Athletes were compensated for their time with a voucher and went into a draw to win a pair of high end running shoes. This experiment was approved by the University of Canterbury's Human Ethics Committee. All participants were treated in accordance with the ethical guidelines.

4.2.2 Materials

All materials were the same as Experiment one.

4.2.3 Procedure

The experiment was conducted on a 200m grass track at Russley Primary School, Christchurch (see figure 9). The track was a flat loop with no obstacles to negotiate. Participants wore their own running clothing and shoes. The track was measured and marked with spray paint at 5 m intervals from a start point on the track. All aspects of the tone counting task and running protocol were conducted in the same manner as experiment 1. Participants completed their own countdown, 3-2-1 and started the counting app, while the researcher started a stop watch. Participants ran continuously around the track for five minutes until the app stopped. The researcher visually measured their final stopping point on the track.

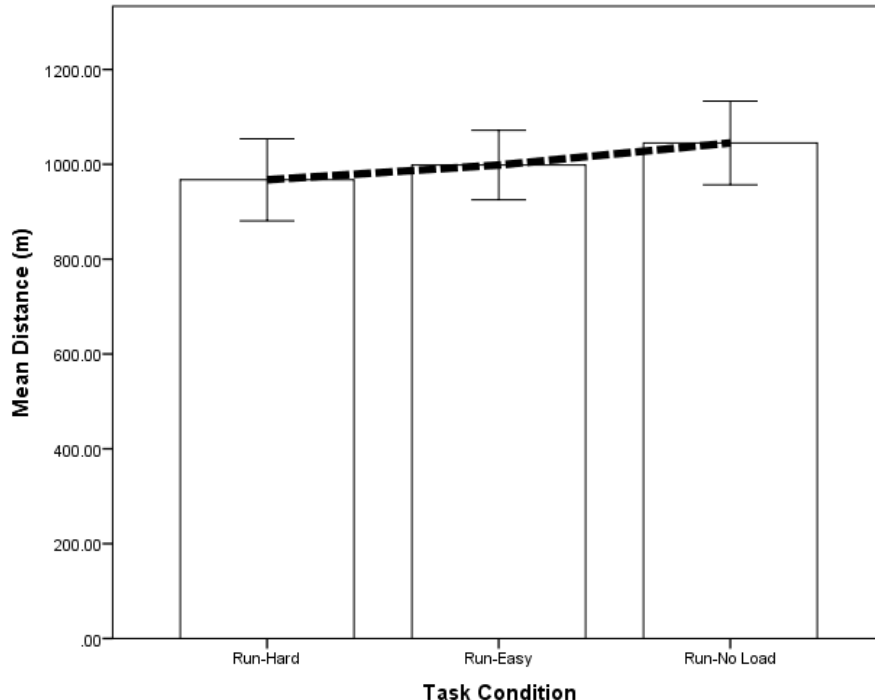
Figure 8: Russley School Track



4.3 Results

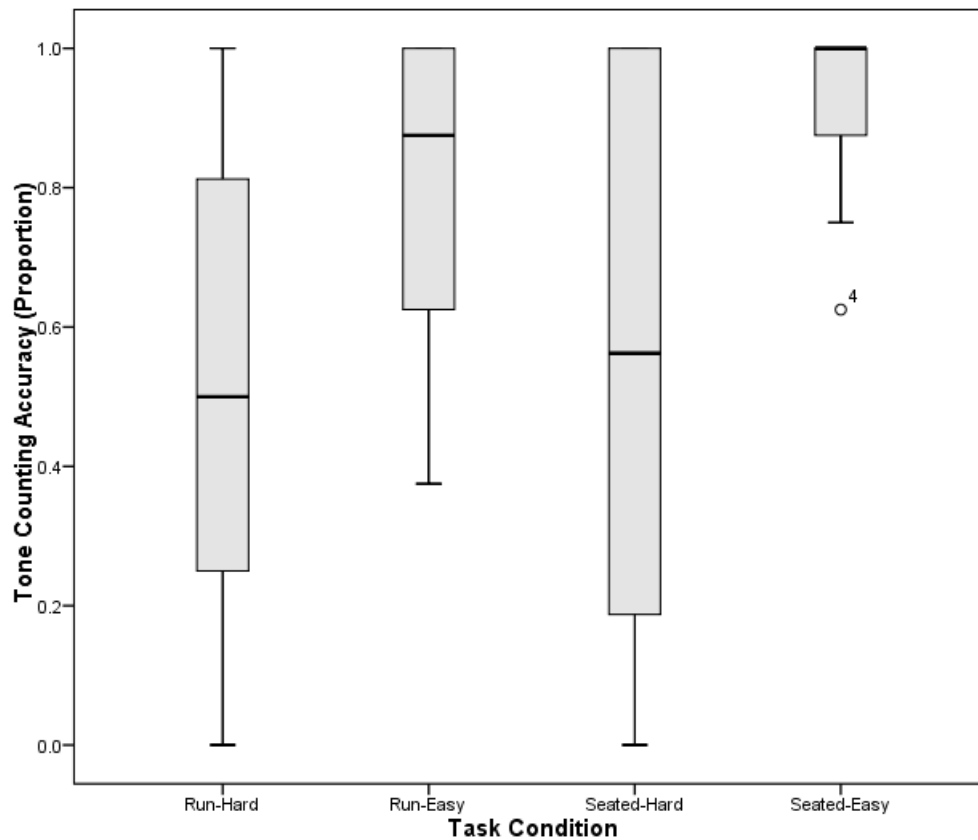
4.3.1 Running Performance. One individual was replaced due to failure to comply with experimental directions. A preliminary inspection of the running performance scores did not indicate any significant deviation from normality (both Kolmogorov-Smirnov and Shapiro-Wilk tests $p > .05$). Therefore, we analysed the scores with a repeated measures analysis of variance (ANOVA). There was a significant main effect for task, $F(2,22) = 5.29$, $p = .013$, $\eta_p^2 = .33$. We performed a trend analysis to test the hypothesis that with decreased cognitive load there would be a trend for increased running distances and there was a significant linear trend as expected, $F(1, 11) = 8.59$, $p = .014$, $\eta_p^2 = .44$. This is displayed in Figure 10.

Figure 9: Mean running distance for the three running tasks for track run (error bars are standard errors of the mean).



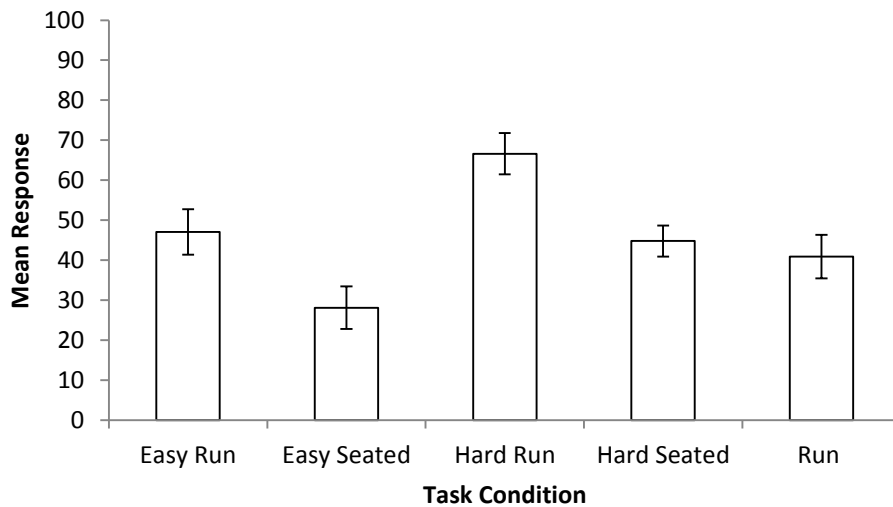
4.3.2 Tone Counting Task. For each participant we calculated the accuracy of the tone counting task for the low frequency tone as this was comparable across all conditions. A preliminary inspection of the tone-counting performance scores indicated significant deviation from normality, both Kolmogorov-Smirnov and Shapiro-Wilk tests $p < .05$. Therefore, we employed Wilcoxon Signed Rank tests to compare differences between the tasks. The primary comparisons of interest were between the dual-task version (tone counting and running) and the equivalent single-task version (tone counting alone). In the case of both the hard task version, $Z = .24$, $p = .809$, $r = .05$, and the easy task version, $Z = 1.61$, $p = .107$, $r = .33$, the difference was non-significant. We also examined the difference between the two running conditions (running hard and running easy) and the two seated conditions (seated hard and seated easy), and these were both significant ($Z = 2.26$, $p = .024$, $r = .46$; $Z = 2.50$, $p = .012$, $r = .51$). The accuracy (proportion correct) performance for all four task conditions is displayed as box-plots in Figure 10.

Figure 10. The accuracy (proportion correct) performance for all four task conditions for the track run



4.3.3 Subjective Workload. The six NASA-TLX items were averaged for each participant for each task to form a composite or global workload score. This global workload score was analysed with a repeated measures ANOVA. There was a significant task main effect, $F(4,44) = 14.30$, $p < .001$, $\eta_p^2 = .57$. Post-hoc Bonferroni corrected comparisons were conducted to further explore this significant effect. Hard run was significantly different from all other tasks, $p < .05$. Easy run was significantly different compared to easy seated, $p < .05$. All other comparisons were not statistically significant, $p > .05$. The mean global workload scores for all tasks are displayed in Figure 11.

Figure 11: Mean global workload scores for the five task conditions (error bars are standard errors of the mean)(Track).

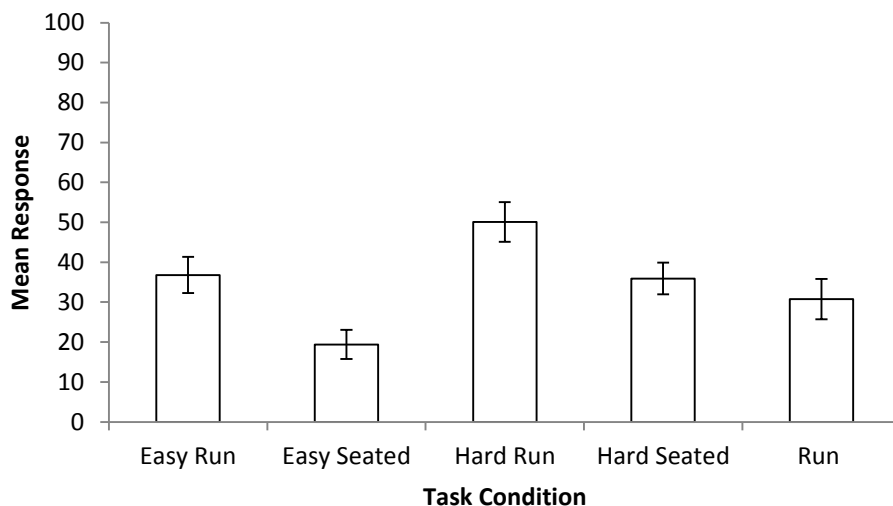


4.3.4 Self-Report Stress State. Principle components Chain-P factor analysis

(varimax rotation) was conducted on the subjective stress state items to examine similarities with Experiment one (for a description of Chain-P see Nunally 1978). P-technique analysis consists of factor analysing the repeated measures from single individuals; when multiple individuals are combined in the analysis this technique is called Chain-P (Baldwin 1946; Cattell et al. 1947; Molenaar 2004; Molenaar and Nesselroade 2009). This technique is useful for uncovering state, as opposed to trait, factors, which is congruent with conceptualizations of stress state. The items were standardized for each participant individually for the 5 tasks (within-subjects z-scores), and then these standardized scores were combined across participants for the analysis (chained). This resulted in 60 records for the factor analysis. A two factor solution was analysed as this was empirically derived in Experiment one. Presented in Table 1 are the resultant rotated pattern matrices. The two component solution, Spent and Task-Focus, collectively explained 50.3% of the variance. Items loading negatively onto a component were reversed scored. The component scores were created by then averaging the remaining items. The Spent component represents the degree to which the participant felt burnt out or exhausted by the task. The Task-Focus component represents the

degree of task-focus the participant reported in response to the task. While task interest and self-related thoughts loadings were less clearly differentiated between the two factors as was the case in Experiment one, for comparative purposes the calculation of the two factors was kept the same (in addition, dropping these two items from the factors made no substantive difference in the subsequent analyses). Both component scores were analysed with repeated measures ANOVA. In the case of Spent there was a significant difference across tasks, $F(4,44) = 12.03$, $p < .001$, $\eta_p^2 = .52$. Post-hoc Bonferroni corrected comparisons were conducted to further investigate this effect. Running under hard cognitive load was significantly different from all other tasks except run only, $p < .05$. Easy seated was also significantly different from hard seated and easy run, $p < .05$. All other comparisons were not statistically significant, $p > .05$. The mean responses for Spent for all five tasks are presented in Figure 12.

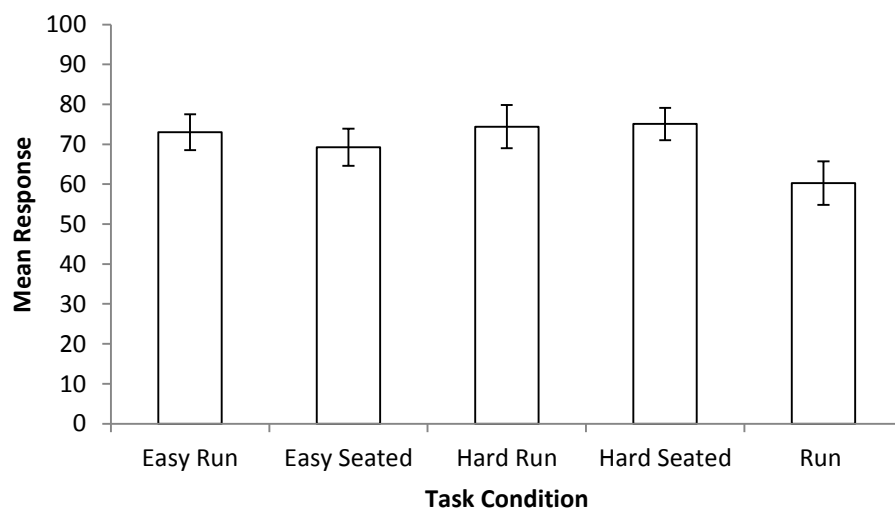
Figure 12: Mean Spent component scores for the five task conditions (error bars are standard errors of the mean)(Track).



In the case of Task-Focus there was a significant difference across tasks, $F(4,44) = 3.29$, $p = .019$, $\eta_p^2 = .23$ [Note: with a Huyn-Felt correction this was $p = .051$]. Post-hoc Bonferroni corrected comparisons were conducted to further investigate this effect. There were, however,

no significant differences, $p > .05$. The mean responses for Task-Focus for all five tasks are presented in Figure 13.

Figure 13: Mean Task-focus component scores for the five task conditions (error bars are standard errors of the mean)(Track).



4.4 Discussion

The results of this experiment demonstrate there is a detriment to running when it is coupled with a secondary cognitive task, similar to experiment one. There is also a linear trend, when the task gets harder, the running becomes slower. However there is no statistically significant effect on the cognitive working memory task. Therefore the first hypothesis is supported however the second is not, as there was no negative effect on the counting task. While these were a different set of runners and therefore direct comparisons between the two experiments may be slightly misleading (they were not randomly assigned to track or trail condition), a tentative conclusion is that trail running is more cognitively demanding than track running. Intuitively this is not surprising, negotiating hazards on paths appears cognitively harder than a flat track, it may also suggest that treadmill studies could be

underestimating the cognitive demands of unconstrained running over uneven terrain (e.g. real running).

Reports of subjective workload uncovered participants found the hard run the hardest, and the easy run harder than the easy seated condition. This supports hypothesis four, which proposed the measure of subjective workload would increase when the tone counting was coupled with running. Particularly comparing the easy run and seated conditions demonstrates the task was exerting a more demanding workload which was the goal of the cognitive task. Participants reported feeling more 'spent' and there was a significant difference across tasks which supports hypothesis five. The hard run was significantly harder than all the tasks except the run only, and easy seated was easier than hard seated and easy run. This is consistent with the notion that as the dual task increased in difficulty, the feeling of being exhausted or spent increased which is consistent with current findings suggesting fatigue is experienced in the brain well before the body (Dietrich & Audiffren 2011). Reports of 'task-focus' were significantly different across tasks but not when compared more closely which tentatively supports hypothesis six. Potentially the task of running can require as much task focus as the dual task requires.

The cognitive task did not produce any significant results for experiment two, unlike experiment one where the hard run significantly affected task accuracy. This could be due to track runners feeling bored or frustrated with the run and using the cognitive task as a form of escape, therefore focusing all their energy on the cognitive task as the distraction. The act of self-control that enforces the running effort causes an inhibitory negative feeling (Muraven & Baumeister 2000). In order to escape this, the runner focuses all their attention instead on

completing the cognitive task, a distraction if you will. This ensures the task is completed successfully, but at the detriment of the running speed.

Similarity between the results of experiment one and two, show trail running and track running produce similar trends for negative effects on running. However, due to there being no significant effect to cognitive functions in experiment two the RAH may not be the best explanation. In fact the results show the opposite of what the RAH predicts which is cognitive performance will be effected before running performance. (Dietrich & Audiffren 2011).

The results from experiment two suggest that track running does not place demands on the executive system (or more specifically working memory). Having ruled out the effects of route selection and decision making demands, there was no significant effect to cognition, which suggests the interference is from something else. Volitionally forcing oneself to run fast may be particularly challenging when our attention or executive resources have been consumed or reallocated to a challenging mental task whether running on a trail or a track. Regardless of the type of running, performance itself was affected in a linear fashion based on difficulty which still suggests there is an executive function resourced to it, the more difficult the task the more interference occurs (Dietrich & Audiffren 2011). Route selection or an element in the trail run effected the counting task in experiment one, for the hard task only and not at all for experiment two, which suggests the trail route may have been more cognitively demanding and therefore taxing this resource more.

5. GENERAL DISCUSSION

Dual task performance affected running speed in both experiments. The trend was linear – the more cognitive task demand, the less running distance covered. In experiment one, the dual running task only impacted the hard cognitive task (statistically speaking). The dual track running task, in experiment two, had no impact at all on the cognitive task (statistically speaking). The results suggest there may be more attentional demand required to trail run, than to run on a flat track, comparisons however are tentative considering the samples were not randomly assigned to conditions.

The RAH model may not be the best way to analyse these results, although the model itself doesn't specifically state directionality, its premise is based on the presumption that exercise affects cognitive function, which has been found for the hard task in experiment one and not at all for experiment two. Also the RAH is based on a review of studies of a longer duration, and given the nature of the current experiments where bouts of acute exercise were compared, it makes comparisons difficult. The RAH is also based on reviews of treadmill running research, trail running and treadmill running have few parallels, according to runners (anecdotal subjective feedback) even the track from experiment two still gave runners a 'free running' experience whereby they could set their own pace. These experiments were based in the real world, working back to the lab, whereas treadmill research stays in the lab. It is challenged that treadmill running, although very valuable, may not be giving us the whole story, and therefore there are few direct comparisons to the literature that the RAH model is based on.

Given the unique challenges trail running produces, for route selection and foot placement, it was initially proposed that impaired performance may be due to an increase in required executive function, by way of decision making. Research shows the substrates for decision making takes place in the prefrontal cortex (Lee et al 2007; Luk & Wallis 2013). The distinction is made between, stimulus and action outcomes, where by decision making can be based on establishing states from stimulus to obtain the best outcome. Value outcomes result by altering or assessing behaviour when it appears to not be advantageous or to reach the desired outcome (Gold et al 2007; Lee et al 2007). Intuitively, both decision making tools may function while trail running. Running only affected the hard cognitive task in experiment one, which could indicate direct interference within the frontal lobes due to the difficulty of both tasks, however given it only affected the hard cognitive task condition, this result requires further investigation. There appears to be an effect to cognition, however whether that be due to a global resource deficit or something more specific is yet to be answered and requires exploration.

Self-regulatory control or vigilance (Langner & Eickhoff 2013) has been linked to regions in the prefrontal cortex, suggesting that even simple repetitive tasks require attentional resources. Vigilant attention, (monotonous, scanning tasks) show a marked decline in performance with time (Langner & Eickhoff 2013). Vigilant attention can be driven by top down processes, including suppressing interfering schema, energising the current task, monitoring implementation and success, which together mediate facilitation. For experiment one, it is possible that running was utilising a vigilant attention resource in order to maintain a constant pace, and the hard cognitive task required a shared resource (central executive). Vigilance experiments, monitoring computer screens for targets while completing a working memory task, can show deteriorating effects after 2 min (Helton et al 2010). This

would further explain the immediate deficit in cognitive function (the task only lasted five minutes) which is not accounted for in the RAH model, which suggests an intermediate duration (at least 20 minutes) to see an effect to cognitive function. To explore this concept further is a matter of trail running for longer durations while completing a dual task.

It has also been demonstrated that working memory tasks, negatively affect vigilance, and that the high cognitive resource demand vigilance places on resources creates a decrement (Helton & Russell 2011). Therefore if the running task was utilising resources to attend to general spatial awareness and gait, this would interfere with its performance when the working memory task is added. This explanation rests on the assumption that running is in fact a vigilance task, it is monotonous and requires scanning however it may be extending the interpretation too far, given the physical demand and the challenging routes of experiment one, it is more plausible for the track run in experiment two. You would also expect if vigilance theory were to be applied to running, that runners from the track run would have experienced the same cognitive deficit as in experiment one.

For the most part, participants reported finding the trail run in the first experiment challenging (regardless of condition). However, only the hard task condition resulted in significant difference. Muraven & Baumeister (2000) suggest findings like this could be due to the demanding suppressive effects of self-regulation. That is, control over oneself, by oneself requires an attentional resource which is limited, and degrades with time (Muraven & Baumeister 2000). Running is physically and mentally demanding, especially the trail chosen here, and maintaining a hard pace, without outside enforcement requires effort. This self-regulation interference, may explain the overall negative effect on running when a cognitive task is added, which makes the runner slow down.

Wickens (2002) states that dual task interference decrements increase, depending on the amount of stages, codes, modalities and channels of visual information that they share. Applying Wickens multiple resource theory to these two experiments results seems logical, the stages of processing dimension would suggest that the working memory task (perceptual and cognitive) and the running task (the selection and execution of action) would not compete for similar resources as much as similar stage processing tasks (Wickens 2008). This could account for the lack of cognitive deficits in these experiments; the cognitive component was not in as much conflict with the execution of action component and therefore is not significantly affected. This does not explain why the running results show such a marked decline in performance, but rather suggests the cognitive task is either dominating a shared resource or running is being affected by something quite different. The multiple resource model, also relates to demand, resource overlap and allocation in order to explain dual task effects. The cognitive demand required for running exceeds resource availability because it is being taxed by the cognitive task or some other demand like volitional control. If volitional control (which is the act of willing) can be explained within the backdrop of this theory as being an execution of action, then it would be in direct conflict with running. This appears to be the best fit to explain the results from these experiments, the cognitive task was not significantly effected in experiment two, however running performance showed a similar deficit to experiment one, the cognitive task and the running task are not competing for the same stage of processing, however volitional control and running are competing at the same stage of processing and therefore show a marked deficit. Regardless, there is also a neurological basis to assume dual tasks create interference and capacity limitations, as demonstrated in monkeys using spatial and working memory dual tasks (Watanabe & Funahashi 2014).

5.1 Practical Applications

More investigation is required before too many inferences can be made regarding the practical outcomes of this type of ecological research. The two groups were not randomly assigned however there is a basis for some suggestions to be made at this point about the potential practical applications. Results from experiment one demonstrated there can be a negative impact on cognition while running due to resource allocation. But the effect on running itself was impacted both experiments. Many occupations require full physical exertion while making executive decisions, military, police and firefighters, are required to negotiate obstacles of a physically demanding nature, remember house or route layout, map reading, all while making executive level decisions. This research demonstrates the potentially limiting effect on an individual's speed performance while carrying out a dual cognitive task, in fact the harder the task the more interference and therefore time taken. Fear words decrease both physical and cognitive performance in rock climbing tasks (Green et al 2013), which demonstrates the potential for further decrement to these occupations while carrying out physical tasks. Clearly interventions need to be developed to ease working memory demands, when coupled with occupations involving whole body exercise. Also, if increased fitness improves performance on dual tasks and creates more performance stability, fitness checks encompassing a dual cognitive task that monitors performance, could also be of benefit (Labelle et al 2013).

These results can also be applied to competitive running. Running was impaired when participants were asked to divert their attention to another stimulus. It is commonplace for coaches to recommend thorough preparation and planning prior to races to avoid interference, by knowing the river and the best line to take, a kayaker can focus all their attention on

performance. An explanation for this could be interference to the implicit system as outlined in the RAH model which states activation of the executive function during whole body exercise, makes movement more forced, and in turn slows it down. Alternatively it could be that the resource required for completing the dual cognitive task was taxing a similar resource required for the hugely computationally demanding task of running. Regardless, surely in the interests of athletes improving their performance it should be noted that tasks requiring cognitive resource from the central executive, should be avoided. The more familiar the track, the more technology used for strategy, and planning, will assist the runner to operate on an implicit effortless level. Anecdotally, the author heard a report of an exceptional runner meditating while running; given EEG results show globally reduced functional interdependence of brain regions while meditating, which could be explained by this implicit system operating at an optimal capacity (Dietrich et al 2011). Investigation of a meditating runner may provide some interesting results for the evolution of the RAH model, particularly in support of the implicit systems performance benefits.

The impact of physical performance and dual cognitive tasks is particularly relevant given the current technology market. Items like google glass (<http://www.google.com/glass/start>) will undoubtedly be used in all physical occupations, such as construction, police, military, search and rescue and any occupation where there is a need for hands free real time reporting of maps, routes or targets. Construction and mining will undoubtedly pick up this technology to improve efficiency and accuracy and to minimise risk, however there are implications for using this dual task technology. The current two experiments have demonstrated there is a running performance decrement when coupled with a working memory task, what will be the impact of having two modalities that share the same resource (visual) during a dual task? It would be expected there would be a significant

amount of interference, the physical task would be affected, however this could also increase the negative cognitive effects also.

5.2 Limitations and Future Research

Running, especially trail running is demanding to the visual system, both ambient (peripheral vision) and focal (object recognition)(Wickens 2008). Wickens (2008) multiple resource model proposes that when a dual task utilises the same modality, especially the visual one, dual task effects will be pronounced. Of particular interest for future ventures would be to test trail running with a secondary visual task using something like google glass. Exploring similar modalities of the visual kind, has been difficult until this point, but advances in this technology, there is an opportunity and need for exploration of the visual field in relation to dual tasks.

It could be suggested that there was some peripheral interference from the visual channel within both experiments and particularly experiment one, if participants chose to look at the buttons on the cell phone as they ran. This was an uncontrolled variable, the buttons are large enough to place all three fingers on all three buttons and only press when a tone is heard. The researcher demonstrated use of the app in this way to participants (see figure 14) however they were free to choose to look at the app and ‘cherry pick’ the buttons if they wished. This could be a source of peripheral interference of the visual field if resources were used to choose buttons, this would account for decreased running performance. However, given decreased running performance was demonstrated on the flat track (where you could run blindfolded) this is less likely to be the case. It could explain the dual task effects in the hard run condition for experiment one, due to increased visual demand from both tasks. However, you would expect the same effects in the dual easy cognitive, running

task if that was the case. It is noted that this limitation may be a cause of peripheral interference and future investigations into the visual field would establish a more accurate measure of this.

Figure 14: Demonstration of cell phone app in use



Establishing an objective fitness level was an omission of the current experiments. Participants self reports indicated they were of good fitness and a record was taken of the types of sporting events they participated in to demonstrate this; however fitness is hugely subjective and varies from week to week. Having a measure of fitness would also be valuable in reporting the results of these studies and make them more comparable to the current research. Labelle (2013) set a peak output and enforced the pace of cyclists, finding the more physical and mental output required the more detriment appears. Although the design of these experiments controlled for fatigue the fitness level of participants was not measured or monitored which is unfortunate given the more physically fit an individual is the more stable and less extreme the results appear to be (Labelle 2013). According to Cozato et al (2014)& Labelle et al (2013), fitness level effects the degree to which impairment occurs. Unfit individuals show a higher level of cognitive impairment than fit individuals in complex decision making tasks, with very fit individuals experiencing a benefit during exercise

(Cozato et al 2014). In the future the researchers would find a more subjective way to gather information on fitness level which makes it comparable to other exercise literature.

Tomporowski & Ellis (1986) state there should be a measure of exercise intensity taken for the duration of exercise. Participants in experiment one and two were advised to “run as fast as you can”(see appendix B for instructions) which could be interpreted as too subjective. It was the chosen method for ecological reasons, by allowing the participant to define their own maximum output; the results are more applicable to real world settings. Given the competitive nature of the runners and the ability to monitor pace of runners, it was thought they would be capable of completing this simple instruction, and they may well have. However this needs to be evidenced by way of heart rate monitor or VO2 max to compare or even discuss the effects of intensity on these two experiments. For this reason, comparisons between the intensity of experiment one (highly demanding uphill trail) and experiment two (easy flat track) cannot be made either. Intuitively the intensity differences may account for the further detriment to the hard cognitive task in experiment one, however without evidence, this is merely speculation. In order to make comparisons on exercise intensity, measures of heart rate will be taken in future endeavours.

The second study was originally designed for a treadmill. Four participants were given the counting task while running on a treadmill and given the same instructions as those on the trail track. Initial results showed they were unable or unwilling to increase or decrease their speed. Participants reported finding a comfortable speed that they could manage and didn't bother adjusting their speed. Therefore there was no measure of distance or speed performance. For this reason it was decided as a consistent comparison to find a flat track which differed only in its visual scanning and decision making requirements. This finding

also supports that volitional resource was conflicting with running speed, when no volitional control was needed the pace stayed the same.

There is a challenge presented to treadmill researchers, any regular trail runner will tell you that running on a treadmill is the most soul destroying boring running task there is, whereas trail running is challenging and fun! Treadmill running and trail running are simply not the same beast, at least not mentally. Fitness research on treadmills or cycle ergometers are extremely valuable however they do not tell the whole story, the focus is on exercise per se, not how the type of exercise affects the brain. As a consequence, these experiments cannot be adequately applied to 'real life' running environments and occupations as easily. The trail and track in the current experiments were chosen for their real life application, in occupations and races, there are distractions, and one must set their own pace, and manage it within the boundaries of their physical and mental capabilities. Working from the environment back to the lab or visa versa will provide a more thorough analysis of the cognitive effects of whole body exercise, especially running.

The current experiments must address the duration of running time. Exercise literature defines duration of exercise as one of the main negative effects to cognition (Dietrich & Audiffren 2011; Cozato et al 2014; Labelle et al 2013). I have previously addressed the reason for using a five minute run time, relating to experimental design; however this does omit the cumulative negative effects of running. This could be another reason for the lack of significant cognitive effect demonstrated in the working memory task. Facilitation of a longer dual counting task like the one used in the current experiments, seems unrealistic, therefore it would be suggested to source a measure of brain activation that can be used over long periods of time, like near functional near-infrared spectroscopy (fNIRS). This would help tease out

the patterns of frontal cortex activation. This device is potentially portable and measures brain oxygenation, and has been successful in the exploration of sustained attention (Carter et al. 2013; De Joux et al. 2013; Ekkekakis 2009; Helton et al. 2010; Helton et al. 2013; Mehta and Parasuraman 2013).

Manipulating motivation can eliminate dual task deficits (Kurzban et al 2013). “Broadly, tasks that involve executive functions show performance decrements over time. Notably rewards improve performance in executive function tasks” (Kurzban et al 2013). Anecdotally, participants in this study commented on their competitive nature which may have been adequate motivation however this warrants further investigation by use of a simple performance reward.

Creative processes can be enhanced by exercise (Cozato et al 2014). During whole body exercise the mind goes into autopilot which is run by the implicit system (Dietrich) Cozato (2014) and colleagues used this to test runners using convergent thinking and divergent thinking tasks. Convergent thinking relies heavily on the top down process in the search for constrained responses and just one answer. Whereas divergent thinking involves searches for many and broad solutions to problems and utilises little top down processes, an example of which is brainstorming. These two processes are thought to be drawn from different areas of executive function and it is suggested exercise can dissect the two. In a group of unfit participants both convergent and divergent thinking was negatively affected by exercise, however fit individuals showed increased performance in divergent thinking (Cozato et al 2014).

5.3 Concluding Statement

These dual cognitive running experiments produced some interesting results for dual task theory. Although there was no effect to cognitive task performance the deterioration of running as cognitive difficulty increased is interesting. The practical applications of producing an ecological experiment, away from the lab, where occupations and sports are actually performed, is progress. Development from this starting point, including utilising current technology like fNIRS and google glass, observing more stringent biochemical measures relating to fitness and intensity, will produce results consistent with treadmill literature, in order for comparisons to be made.

6. REFERENCES

- Baldwin AL (1946) The study of individual personality by means of the intraindividual correlation. *J Personal* 14:151–168
- Beilock SL, Carr TH, MacMahon C, Starkes JL (2002) When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *J Exp Psychol Appl* 8:6-16
- Boecker H, Sprenger T, Spiker ME, Henrikson G, Koppenhoefer M, Wagner KJ, Valet M, Berthele A, Tolle TR (2008) The runner's high: opioidergic mechanisms in the human brain. *Cerebral Cortex* 18: 2523-2531
- Bourke PA, Duncan, Nimmo-Smith (1996) A general factor involved in dual task performance decrement. *Q J Exp Psychol A* 49: 525-545
- Boutcher SH, Lander DM (1988) The effects of vigorous exercise on anxiety, heart rate, and alpha enhancement of runners and non-runners. *Psychophysiology* 25: 696-702
- Brill JC, Mouloua M, Hancock PA, Gilson RD, & Kennedy RS (2003) Demonstrating a methodology for assessing cognitive capacities across sensory systems: M-SWAP. *Proceedings Hum Factors Ergonomics Society* 47:852-854
- Carter L, Russell PN, Helton WS (2013) Target predictability, sustained attention, and response inhibition. *Brain Cognit* 82:35-42
- Cattell RB, Cattell AKS, Rhymer RD (1947) P-technique demonstrated in determining psychophysiological source traits in a normal individual. *Psychometrika* 12:267–288
- Colzato LS, Szaporo A, Pannekoek JN, Hommel B (2013) The impact of physical exercise on convergent and divergent thinking. *Frontiers in Human Neuroscience* 7:1-6
- De Joux N, Russell PN, Helton WS (2013) A functional near-infrared spectroscopy study of sustained attention to local and global target features. *Brain Cogn* 81:370-375

- Dietrich A (2006) Transient hypofrontality as a mechanism for the psychological effects of exercise. *Psychiat Res* 145:79–83
- Dietrich A, Audiffren M (2011) The reticular-activating hypofrontality (RAH) model of acute exercise. *Neurosci Biobehav R* 35:1305–1325
- Dietrich A, Mc Daniel WF (2004) Endocannabinoids and exercise. *Sports Med* 38: 536-541
- Dietrich A, Sparling PB (2004) Endurance exercise selectively impairs prefrontal-dependent cognition. *Brain Cognit* 55:516–524
- Dietrich L, Faber PL, Tei S, Pascual-Marqui RD, Milz P, Kochi K (2011) Reduced functional connectivity between cortical sources in five meditation traditions detected in lagged coherence using EEG tomography 60:1574-1586
- Ekkekakis, P (2009) Illuminating the black box: Investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. *J Sport Exercise Psychol* 31:505–553
- Etnier JL, Slazar E, Landers DM, Peruzzello SJ, Han M, Nowell P (1997) The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. *Journal of Sports & Exercise Psychology* 19: 249-277
- Field AP (2013) *Discovering statistics using IBM SPSS statistics*. Los Angeles. Sage
- Fentom, PH (1994) Benefits of exercise in health and disease. *British Medical Journal* 308: 1291-1295
- Gold JI, Shadlen MN (2007) The neural basis of decision making. *Annual Review of Neuroscience* 30: 535-574
- Green AL, Helton WS (2011) Dual-task performance during a climbing traverse. *Exp Brain Res* 215:307-313
- Green AL, Draper N, Helton WS (2013) The impact of fear words in a secondary task on complex motor performance: a dual-task climbing study. *Psychol Res* 1-9

- Hart SG, Staveland LE (1988) Development of NASA-TLX (task load index): results of empirical and theoretical research. In P Hancock & N Meshkati (Eds.), Human mental workload (pp. 139–183). Amsterdam: North-Holland
- Helton WS, Matthews G, Warm JS (2009) Stress state mediation between environmental variables and performance: the case of noise and vigilance. *Acta Psychol* 130:204–213
- Helton WS, Ossowski U, Malinen S (2013) Post-disaster depression and vigilance: a functional near-infrared spectroscopy study. *Exp Brain Res* 226:357-362
- Helton WS, Russell PN (2011) Working memory load and the vigilance decrement. *Exp Brain Res* 212:429–437
- Helton WS, Russell PN (2013) Visuospatial and verbal working memory load: effects on visuospatial vigilance. *Exp Brain Res* 224:429-436
- Helton WS, Warm JS (2008) Signal salience and the mindlessness theory of vigilance. *Acta Psychol* 129:18–25
- Helton WS, Warm JS, Tripp LD, Matthews G, Parasuraman R, Hancock PA (2010) Cerebral lateralization of vigilance: a function of task difficulty. *Neuropsychol* 48:1683–1688
- Hollman JH, Youdas JW, Lanzino DJ (2009) Gender differences in dual task gait performance in older adults. *American Journal of Men's Health* 5:11-17
- Horrey WJ, Wickens CD, Consalus KP (2006) Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. *J Exp Psychol: Appl* 12:67-86
- Kennedy RS, Bittner AC (1980) Development of performance evaluation tests for environmental research (PETER): complex counting test. *Aviation, space, and environmental medicine*, 51:142-144
- Kubitz KA, Pothakos K (1997) Does aerobic exercise decrease brain activation? *Journal of Sport & Exercise Psychology* 101:291-301

- Kurzban R, Duckworth A, Kable JW, Myers J (2013) An opportunity cost model of subjective effort and task performance. *Behavioural and Brain Sciences*, 36: 661-726
- Labelle V, Bosquet L, Mekary S, Bherer L (2013) Decline in executive control during acute bouts of exercise as a function of exercise intensity and fitness level. *Brain Cognit* 81:10-17
- Lambourne K, Tomporowski P (2010) The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. *Brain Res* 134:12-24
- Langner R, Eickhoff, SB (2013) Sustaining attention to simple tasks: A meta-analytic review of the neural mechanisms of vigilant attention. *Psychol Bull* 139:870-900
- Langner R, Willmes K, Chatterjee A, Eickhoff SB, Sturm W (2010) Energetic effects of stimulus intensity on prolonged simple reaction-time performance. *Psychol Res* 74:499-512
- Lee D, Mathews FS, Rushworth ME, Masataka W, Masamichi S (2007) Functional specialisation of the primal frontal cortex during decision making. *The Journal of Neuroscience* 31: 8179-8173
- Lindenberger U, Marsiske M, Baltes PB (2000) Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psycholog Aging*: 15:417-436
- Luk CH, Wallis JD (2007) Choice coding in frontal cortex during stimulus guided or action guided decision making. *The Journal of Neuroscience* 33:1864-1871
- Matthews G, Campbell SE, Falconer S, Joyner LA, Huggins J, Gilliland K (2002) Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emot* 2:315–340
- Matthews G, Davies DR (2001) Individual differences in energetic arousal and sustained attention: A dual-task study. *Pers Indiv Differ* 31:575-589

- Matthews G, Warm JS, Reinerman-Jones LE, Langheim LK, Washburn DA, Tripp L (2010) Task engagement, cerebral blood flow velocity, and diagnostic monitoring for sustained attention. *J Exp Psychol: Appl* 16:187
- McMorris T, Graydon J (1997) The effect of exercise on cognitive performance in soccer-specific tests. *J Sports Sci* 15:459-468
- McMorris T, Hale BJ (2012) Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: A meta-analytical investigation. *Brain Cognit* 80:338-351
- Mehta RK, Parasuraman R (2013) Effects of mental fatigue on the development of physical fatigue: a neuroergonomic approach. *Hum Factors*
- Molenaar PCM (2004) A manifesto on psychology as idiographic science: bringing the person back into scientific psychology, this time forever. *Measurement* 2:201-218
- Molenaar PCM, Nesselroade JR (2009) The recoverability of P-technique factor analysis. *Multivariate Behav Res* 44:130-141
- Muraven M, Baumeister RF (2000) Self-regulation and depletion of limited resources: Does self-control resemble a muscle?. *Psychol Bull* 126:247-259
- Navon, D., D. Gopher, (1979). On the economy of the human processing systems. *Psychological Review*, 86, 254-255
- Nunnally JC (1978) *Psychometric theory* (2nd ed). New York, NY: McGraw Hill
- Salmon, P (2001) Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. *Clinical Psychology Review* 21, 33-61
- Shields, M. R., Larson, C. L., Swartz, A. M., & Smith, J. C. (2011). Visual threat detection during moderate-and high-intensity exercise. *Emot* 11:572
- Tomprowski PD (2003) Effects of acute bouts of exercise on cognition. *Acta Psycholog* 112:297-324

- Tomprowski PD, Ellis NR (1986) Effects of exercise on cognitive processes: A review. Psychol Bull 99:338
- Vissing J, Anderson M, Diemer NH (1996) Exercise-Induced Changes in Cerebral Glucose Utilization in the Rat. Journal of Cerebral Blood Flow and Metabolism 16: 729-736
- Watanabe K & Funahashi S (2014) Neural mechanisms of dual-task interference and cognitive capacity limitation in the prefrontal cortex. *Nature Neuroscience*. doi:10.1038/nn.3667
- Wickens CD (1976) The effects of divided attention on information processing in manual tracking. J Exp Psychol: Hum Percept Perform, 1-13.
- Wickens C (2002) Multiple resources and performance prediction. Theor Issues Ergonomics Sci 159-177
- Wickens CD (2008) Multiple resources and mental workload. Hum Factors 50: 449-455
- Wickens C, McCarley J (2008) Time sharing and multiple resource theory. In Wickens, & McCarley, Applied Attention Theory. Boca Raton: Taylor & Francis Group
- Woodworth RS, Schlosberg H (1955) Attention. In R. S. Woodworth, & H. Schlosberg, Experimental Psychology (pp. 72-106). London: Methuen & Co. Ltd.
- Yogev-Seligmann G, Rotem-Galili Y, Mirelman A, Dickstein R, Giladi N, Hausdorff JM (2010) How does explicit prioritization alter walking during dual-task performance? Effects of age and sex on gait speed and variability. Phys Ther 90:177–186



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Born to Run - Information Sheet

My name is Megan Blakely, I am completing my masters project on the cognitive effects of trail running. This research is investigating the cognitive effects of whole body exercise on a counting task. You will be asked to complete four, five minute runs while you complete the counting task. You will also be asked to complete three counting tasks while seated. The distance you run and the accuracy on the counting task will be measured and recorded. It is expected that it will take an hour for you to complete all the tasks. The running track is undulating, has varied terrain like tree roots, steps and uneven surfaces which you should be aware of at all times. You will be required to wear a helmet for your protection which will also part of the listening apparatus.

You may receive a copy of the project results by contacting the researcher at the conclusion of the project. Participation is voluntary and you have the right to withdraw at any stage without penalty. If you withdraw, I will remove information relating to you. You will have to request this within two months of participation or your results become part of the thesis. The results of the project may be published, but you can be assured of the complete confidentiality of the data gathered in this research. To ensure anonymity and confidentiality, your name will be replaced by a number and will not be recorded with any of the results. The data will be securely stored on a password protected laptop. The data will only be used to produce statistical analysis for this project and may be used for continuing research of the same nature. A thesis is a public document and will be available through the UC Library.

The project is being carried out as part of a Masters degree in Psychology by Megan Blakely under the supervision of Deak Helton. He/she/they will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz). If you agree to participate in the study, you are asked to complete the consent form and return to the researcher.

Psychology Department

Email: mbl26@canterbury.ac.nz

Born to Run - Consent Form

I have been given a full explanation of this project and have had the opportunity to ask questions.

I understand what is required of me if I agree to take part in the research.

I understand that participation is voluntary and I may withdraw at any time without penalty.

Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

I understand that any information or opinions I provide will be kept confidential to the researcher and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.

I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

I understand the risks associated with taking part and how they will be managed.

I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

I understand that I can contact the researcher, Megan Blakely at mbl26@canterbury.ac.nz or supervisor Deak Helton for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project.

Name:

Date:

Signature:

Please return your form to the researcher.

APPENDIX B

Script for Counting Task: AUDITORY

PRACTICE

“For this task, you will be presented with a random series of three pitched tones: low, middle, and high. Your task is to count the number of times you hear the low tone, and press the low tone button after every fourth tone. You might occasionally think there is a pattern, but there really isn’t one - you really have to count. Do you have any questions? This time you’re doing this for practice. Please put the headphones on now.”

LOW DEMAND

“For this task, you will be presented with a random series of three pitched tones: low, middle, and high. Your task is to count the number times you hear the low tone, and press the low tone button after every fourth one. Do you have any questions? Please put the headphones on now.”

HIGH DEMAND

“For this task, you will be presented with a random series of three pitched tones: low, middle, and high. Your task is to count the number of low, middle, and high tones, and press the low, middle and high tone buttons, respectively, after every fourth one. This means you need to count the number of times you hear the low tone and press the low tone button after every fourth one, while simultaneously counting the number of times you hear the middle tone and pressing the middle tone button after every fourth one, and likewise pressing the high tone button after every fourth high tone. Do you have any questions? Please put the

headphones on now.”

RUNNING TASKS

For this task you will be required to run as fast as you can up this trail (on this track) for five minutes. (You are required to do this while you complete the counting task, [when dual task is required]) Please do not intentionally slow down or pace yourself at any stage. Any questions?

APPENDIX C

MALE or FEMALE (circle one)

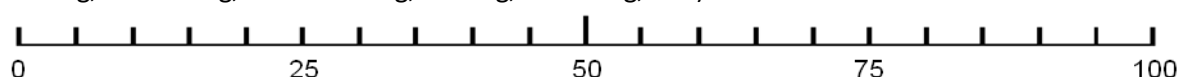
Age: _____

Years of Running Experience: _____

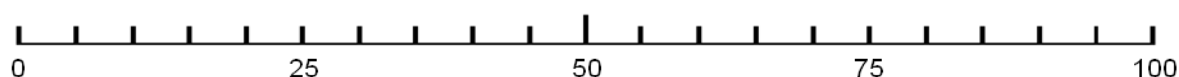
Best running event/s: _____

For the following items use the response scale below the item by circling the vertical line closest to your answer; the scale goes from 0 (**very low**) to 100 (**very high**). These questions refer to you experience during the task.

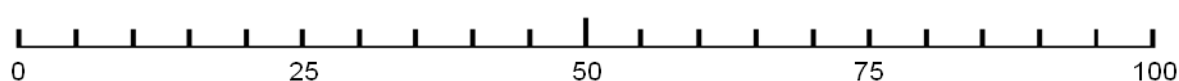
1. **Mental Demand** - How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)?



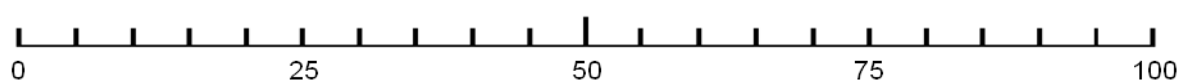
2. **Physical Demand** - How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)?



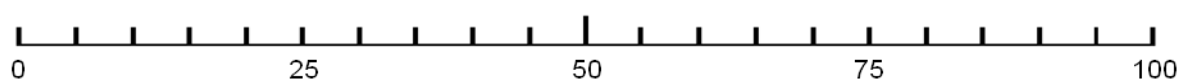
3. **Temporal Demand** - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?



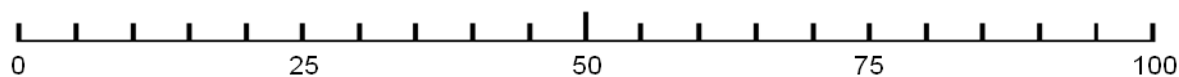
4. **Emotional Demand** – How emotionally demanding was the task?



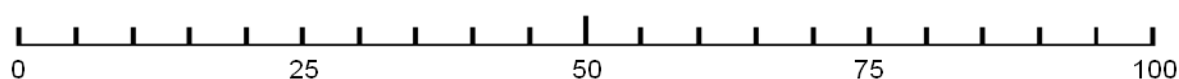
5. **Performance Monitoring Demand** – How much did the task require you to monitor your performance?



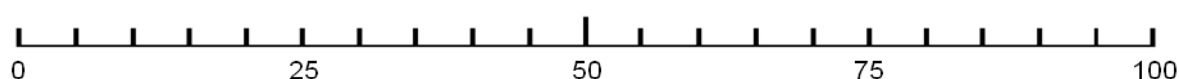
6. **Effort** – How hard did you have to work to accomplish your level of performance?



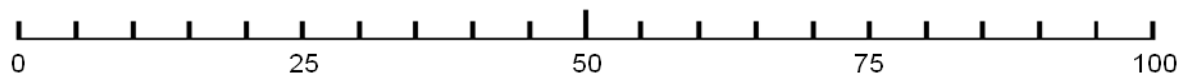
7. **Physical Fatigue** – How physically exhausted and tired did you feel?



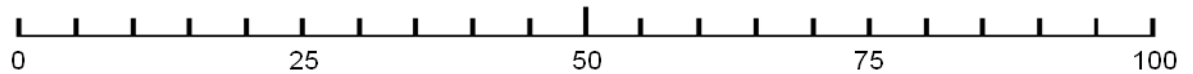
8. **Mental Fatigue** – How mentally exhausted and tired did you feel?



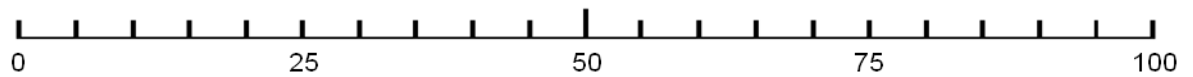
9. **Tense** – How tense or anxious did you feel?



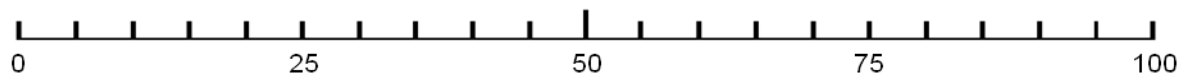
10. **Unhappy** – How unhappy did you feel?



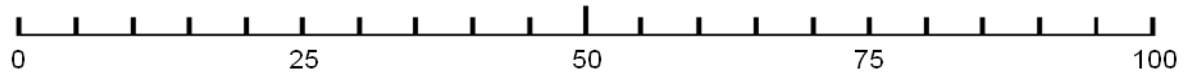
11. **Motivation** – How motivated were you to do well?



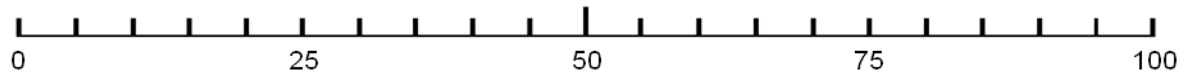
12. **Task Interest** – How interesting was the task?



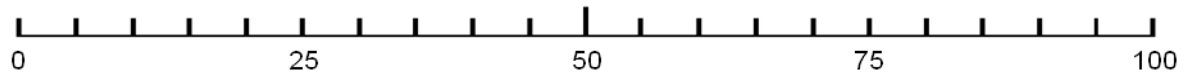
13. **Self Related Thoughts** - How much did you think about yourself?



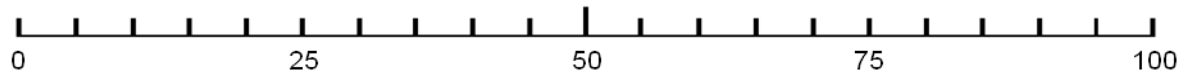
14. **Concentration** – How focused on the task were you?



15. **Confidence** – How confident were you during the task?



16. **Task Related Thoughts** - How much did you think about the task?



17. **Task Unrelated Thoughts** – How much did you think about something other than the task?

